This report was prepared by Frances Robbins, R.E. Johnson, and Janet Harris

I. PERSONNEL

Table I.1 lists all persons who worked under this grant, 1 July 1965 to 30 June 1967, including several whose salaries were not paid from this grant, but by the University of Illinois.

II. RESEARCH AIMS

This project envisaged a comprehensive study of the chemical and physical properties of human sweat produced by a combination of heat exposure and exercise on a motor-driven treadmill.

The first six months (1 July - 31 December 1965) were spent establishing protocols and validating methods. (See semi-annual status report no. 1, for 1 July 1965 - 31 December 1965.)

During the second six months (1 January-30 June 1966), two major questions were asked: (1) Can the freezing point of eccrine sweat be accounted for in terms of the commonly measured substances - urea, ammonia, lactate, chloride, sodium, and potassium? (2) What is the viscosity of sweat? Three primarily methodological studies were started: (1) the appropriate methods for collecting and processing sweat; (2) acid-base properties of sweat; and (3) the secretory pressure of individual sweat glands.(See semi-annual status report no. 2, for 1 January 1966 - 30 June 1966).

Three main research programs were followed during the period July 1 to December 31, 1966: (1) the relationship between the rate of sweating and the chemical composition of sweat; (2) a comparison of the chemical composition

TABLE I.1. PERSONNEL ASSOCIATED WITH NASA GRANT NGR 14-005-050

Name and Title	Period of Association	Percentage of Salary Paid from this Grant
R. E. Johnson, Professor	1 July 1965 - 30 June 1967	0
F. Sargent II, Professor	" "	0
Mrs. Frances Robbins, Biochem. Technologist	" "	[illegible]
T. Morimoto, Res. Assoc.	1 Sept. 1965 - 31 Oct. 1966	100
RESEARCH ASSISTANTS:		
Mrs. Keun Shil Shin	1 Sept. 1965 - 14 June 1966	100
Melinda Brookens	12 March 1966 - 17 June 1966	100
Georgiana Benner	16 June 1966 - 10 Sept. 1966 1 Feb. 1967 - 13 June 1967	100
Ruth V. Chalmers	1 Sept. 1966 - 1 Mar. 1967	50
Sharon Vernon	16 June 1967 - 30 June 1967	100
GRADUATE ASSISTANTS:		
Barrie Blase	1 Sept. 1965 - 14 June 1966	0
Janet Harris	16 June 1966 - 15 Aug. 1966 16 June 1967 - 30 June 1967	100
Diane Wakat	16 June 1966 - 15 Aug. 1966	100
Paul Molé	16 June 1966 - 30 June 1967	100
Barbara Johnson	16 Sept. 1966 - 31 Jan. 1967 1 Feb. 1967 - 15 June 1967	50 25
William Kachadorian	16 June 1966 - 31 Aug. 1966	25
Joseph Nelson	" - 4 Aug. 1966	25
Mrs. Helen Sandberg	16 Sept. 1966 - 30 Sept. 1966	50

TABLE I.1 (Continued)

Name and Title	Period of Association	Percentage of Salary Paid from this Grant
LABORATORY ATTENDANT:		
Jackie Davis	16 June 1966 - 27 Aug. 1966	100
Carrol Vasser	16 June 1966 - 30 June 1967	100
CLERK-TYPISTS:		
Mrs. Susan Kinney	27 Sept. 1965 - 17 April 1966	25
Mrs. Hazel Roosevelt	18 April 1966 - 1 Nov. 1966	25

In addition to those listed, there were research subjects who worked from time to time as needed. These included: S. Berger, B. Blase, J. Bodammer, K. Leoni, U. Mazumdar, J. Miliszkiewicz, P. Molé, J. Nommensen, C. Trayser, and C. Tenczar.

of sweat collected in impermeable bags on the arms, with that collected from the naked skin of the whole body where it had evaporated; and (3) the development of a system for collecting expired gas, storing it without appreciable loss of carbon dioxide, and analyzing its composition. (See semi-annual status report no. 3 for 1 July 1966 - 31 December 1966.)

From January 1 to June 30, 1967, the clearance ability of the sweat glands was compared with that of the kidneys. In Section IV, the total solids of the sweat are discussed. The clearances of creatinine and urea by the kidney and by the sweat glands are compared in Section V. The excretion of anions, cations and other solutes in the sweat is presented in Section VI. Section VII attempts a generalization on factors related to the excretion of solutes.

III. METHODS

With two additions, the chemical methods used to collect the data presented in this report are the same as in progress report No. 3 for the period 1 July 1966 - 31 December 1966. These additions are methods for hydrolyzable sulfur and neutral sulfur, and a gravimetric method for estimating total solids. All methods are listed in Table III.1, with a reference and a brief identification of the principal.

Considerable attention was given to the treatment of the skin before collecting arm sweat and to the method of processing the sweat prior to analysis. The following procedure was finally adopted: shaving the skin with an electric razor (Schick) 24 hours ahead of the experiment; washing the skin with neutral, non-allergenic detergent (Vel); rinsing with distilled water; and starting actual collection 10 minuter after the onset of sweating. Clear, non-turbid sweat was obtained by freezing, thawing, and then centrifuging. Chemical analyses were performed within 2 days after clear sweat was obtained. (Report No.2, pp. 4-8.)

The system for collecting total body sweat that had been standardized (Report No. 3, pp. 3-5.) was used throughout these experiments.

An improved method was used systematically for measuring oxygen consumption and carbon dioxide production. (Johnson, R.E., Frances Robbins, R. Schilke, P. Molé, Janet Harris, and Diane Wakat: A versatile system for measuring oxygen consumption in man. J. Appl. Physiol. 22: 377-379, February, 1967.)

The experiments were designed so that two subjects walked on a level treadmill for two hours a week for six weeks. The room conditions were varied between experiments so that the heat stress was increased progressively from walk 1 to walk 2 to walk 3, reverted to the conditions of walk 1 in walk 4, and then rose progressively from

TABLE III.1. CHEMICAL AND PHYSICAL METHODS FOR STUDYING THE COMPOSITION OF HUMAN SWEAT. SUMMER 1966. (NASA GRANT NGR 14-005-050).

Substance	Authors	Type of Method
Total Nitrogen	Koch and McMeekin, 1924; Davenport, 1926	Acid digestion, nesslerization, colorimetry
Urea Nitrogen	Van Slyke and Cullen, 1914	Urease, aeration, nesslerization, colorimetry
Ammonia Nitrogen	Van Slyke and Cullen, 1914.	Aeration, nesslerization, colorimetry
Na, K	White, 1952; Baird Assoc., 1953	Flame photometry
Chloride	Cotlove, Trantham, and Bowman, 1958; Am. Inst. Co., 1960	Aminco-Cotlove Titrator
Osmolarity	Wesson, 1952; Fiske Assoc., 1954	Freezing point (Fiske osmometer)
Lactic Acid	Hawk, Oser, and Summerson, 1951	Copper liming, colorimetry
Ca, Mg	Kovács and Tárnoky, 1959; Evans, Lt., 1966	Chelation, titration atomic absorption spectrophotometry
Viscosity	Cannon and Fenske, 1938	Capillary tube
Density	Cannon and Fenske, 1938	Pycnometer
Total CO_2 and HCO_3	Consolazio, Johnson, and Pecora, 1963	Manometry
pH	Clark, 1928; Bates, 1954	Glass electrode
Freeze drying	Hansen and Robbins, 1954	Vacuum plus solid CO_2 freezing
Collection and processing	Robinson and Robinson, 1958	Several techniques

TABLE III.1 (continued)

Substance	Authors	Type of Method
Inorganic Sulfur	Berglund and Sörbo, 1960	Turbidimetric
Hydrolyzable Sulfur	Folin, 1905	Turbidimetric
Total and Neutral Sulfur	Alicino, 1958	Oxidation and turbidimetric
	Steyermark, et al., 1961	

walk 5 to walk 6. The details of room conditions, subject response to thermal stress, and calorie expenditure have been given in Progress Report No. 3, 1 July 1966 - 31 December 1966; Tables III.5, III.6A, III.6B, III.7A, and III.7B.

Generally speaking, the heat stress was correlated with rate of sweating, neither subject ever developed heat exhaustion, and the two series of walks gave data quite comparable with each other for a given subject.

IV. TOTAL SOLIDS IN SWEAT

The results for total solids in arm sweat are shown in Table IV.1A for the first subject, and Table IV.1B for the second.

In all specimens, the measured total solids was greater than the total solids calculated from the sum of the measured solutes. This can only mean that not all of the individual solutes were measured. We look at the "residual nitrogen" as a possible source for this difference. This value is the difference between the total N and the N from urea and ammonia. This residue could be accounted for by amino acids, among other possibilities.

The total solids should roughly correlate with the osmotic pressure. Only in a general way was this true for our subjects. On the other hand, a plot of total solids as calculated from the measured solutes against osmotic pressure calculated from total solids should be very close to linear, as the same measurements are used to calculate both variables. This discrepancy between calculated and measured values again suggests that not all quantitatively important molecules have been measured.

V. CLEARANCE OF CREATININE AND UREA BY THE KIDNEYS AND SWEAT GLANDS

Much attention has been paid to the renal clearance of both creatinine and urea, but relatively few observers have studied urea excretion in the sweat. There are very few studies of the excretion of creatinine in the sweat. In kidney physiology, creatinine clearance is usually accepted as a measure of glomerular filtration rate; urea clearance is of the same order of magnitude, but smaller. We have compared the excretion of creatinine and urea by the kidneys and the sweat glands to see if the concept of clearance might be usable for the sweat glands.

TABLE IV.1A. CHEMISTRY OF ARM SWEAT: TOTAL SOLIDS, CONCENTRATION. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: KACH

CONSTITUENT		EXPERIMENT					
NAME	UNIT mg/L	29 June	6 July	13 July	20 July	27 July	3 Aug
Na		863	1208	1254	955	897	1047
K		222	199	203	199	148	199
Mg		4	2	1	2	1	5
Ca		18	4	8	10	6	6
Cl		1111	1665	1722	1253	1345	1537
Lactate		1485	1143	1098	1359	1350	1242
NH_3		24	36	34	43	29	36
Urea		300	468	474	468	378	480
Sum		4026	4724	4793	4288	4155	4551
Total Measured Solids		5380	5480	5590	4730	4990	5380
Total Solids Deficit*		1354	756	797	442	835	829
Osmolarity mOsm/L							
Calculated		98.6	127.5	130.8	108.0	104.1	118.5
Measured		105.0	118.0	127.0	103.0	115.0	115.0
Deficit*		+6.4	-9.5	-3.8	-5.0	+10.9	-3.5

*Deficit is defined as (measured) - (calculated from sum of solutes)

(Refer to Report No. 3, Table IV.9)

TABLE IV.1B CHEMISTRY OF ARM SWEAT: TOTAL SOLIDS, CONCENTRATION. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT: NEILS

CONSTITUENT		EXPERIMENT					
NAME	UNIT mg/L	30 June	7 July	14 July	21 July	28 July	4 Aug
Na		1242	1093	1495	978	794	1403
K		238	273	199	211	195	218
Mg		10	5	5	8	5	4
Ca		16	10	2	8	4	6
Cl		1700	1441	2084	1324	1090	1963
Lactate		1323	1224	1170	1350	1305	1422
NH_3		60	31	36	53	36	36
Urea		696	618	534	684	570	624
Sum		5284	4694	5524	4615	3998	5676
Total Measured Solids		6580	5650	6340	5830	4750	6610
Total Solids Deficit		1296	956	816	1215	752	934
Osmolarity mOsm/L							
Calculated		139.4	121.7	153.3	115.8	96.9	150.8
Measured		139.0	138.0	146.0	113.0	117.0	148.0
Deficit *		-0.4	+16.3	-7.3	-2.8	+20.1	-2.8

*Deficit is defined as (measured) - (calculated from sum of solutes)

(Refer to Report No. 3, Table IV.9)

The values for arm bag sweat volume, body sweat volume, total sweat volume and urine volume for specimens all collected over the same period are given in Table V.1. The total loss of water in these experiments was from 5 to 10 times larger in the sweat than in the urine.

The renal clearance for creatinine is given in Table V.2; that for urea is given in Table V.3. The creatinine clearance values were larger in Subject KACH than in Subject NELS. The correlations for the kidney clearances of the two molecules were close, creatinine clearance generally being the larger.

The creatinine clearances for arm sweat are given in Table V.4, for total body sweat, in Table V.6. For urea the corresponding tables are Tables V.5 and V.7. Arm sweat and total body sweat lead to similar conclusions: the urea clearance is always far higher than the creatinine clearance, and by a factor of 20 to 50. Generally speaking, the rate of sweating has no correlation with creatinine clearance. By contrast, the urea clearance tends to rise with rising sweat rate.

Absolute values for creatinine clearance in the kidneys, arm sweat and total body sweat are given in Table V.8. Those for urea are given in Table V.9. To make possible a mathematically reasonable comparison between the kidney and sweat glands, values were calculated on the basis of body surface area. For creatinine the data are given in Table V.10 and for urea in Table V.11. With this kind of formulation, the values for arm sweat and total body sweat become comparable, and so the term "sweat glands" can apply to either. With respect to creatinine clearance, the kidneys are higher than the sweat glands by a factor of 100 to 400 (Table V.10). With respect to urea clearance, the values for the kdineys are higher but only by a factor of from 1 to 7 (Table V.11). When comparison is made for a single gland type, the renal clearance of creatinine is roughly the same or a little larger than that of urea. By contrast, for the

TABLE V.1. RATES OF EXCRETION, ARM SWEAT, BODY SWEAT, TOTAL SWEAT, AND URINE COLLECTION DURING 70 MINUTES OF WALKING. (UNITS ARE ml/min). SUMMER 1966. (NASA GRANT NGR 14-005-050).

Subject	Arm Sweat	Body Sweat	Total Sweat	Urine
KACH	1.18	10.67	11.87	0.79
	1.83	12.57	14.41	3.67
	2.38	16.87	19.26	2.26
	1.18	10.32	11.50	2.33
	1.58	14.03	15.62	2.88
	1.83	15.97	17.81	1.43
NELS	0.62	8.89	9.50	2.73
	1.30	13.20	14.50	1.74
	1.52	16.32	17.82	2.86
	0.83	10.32	11.17	4.29
	1.10	13.50	14.61	2.85
	1.33	16.15	17.49	1.75

TABLE V.2. RENAL CLEARANCE OF CREATININE AFTER WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	CREATININE In Plasma μg/ml	In Urine μg/ml	μg/min	Clearance ml/min
KACH	29 June	8.40	295	885	105
	6 July	8.82	400	1468	166
	13 July	9.80	590	1770	181
	20 July	9.24	543	1629	176
	27 July	9.52	535	1605	169
	3 Aug	9.52	345	1035	109
NELS	30 June	13.64	343	1029	75
	7 July	13.64	243	729	53
	14 July	12.88	268	804	62
	21 July	9.66	245	1051	109
	28 July	10.36	335	1005	97
	4 Aug	11.76	213	639	54

TABLE V.3. RENAL CLEARANCE OF UREA AFTER WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	UREA In Plasma* µg/ml	In Urine µg/ml	µg/min	Clearance ml/min
KACH	29 June	133	4111	12331.80	93
	6 July	133	4948	18159.89	137
	13 July	133	6683	20050.20	151
	20 July	133	6812	20435.40	154
	27 July	133	7133	21398.40	161
	3 Aug	133	3920	11759.40	88
NEIS	30 June	174	5743	17227.80	99
	7 July	174	3076	9228.60	53
	14 July	174	3290	9871.20	57
	21 July	174	4019	17240.65	99
	28 July	174	4471	13411.80	77
	4 Aug	174	2861	8584.20	49

*Plasma urea was measured on 3 Aug and 4 Aug without correction for ammonia.

TABLE V.4. SWEAT GLAND (ARM) CLEARANCE OF CREATININE DURING WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	CREATININE In Plasma µg/ml	CREATININE In Arm Sweat µg/ml	CREATININE In Arm Sweat µg/min	Clearance ml/min
KACH	29 June	8.40	1.00	1.18	0.14
	6 July	8.82	0.64	1.17	0.13
	13 July	9.80	0.75	1.78	0.18
	20 July	9.24	0.53	0.63	0.07
	27 July	9.52	0.64	1.17	0.12
	3 Aug	9.52	0.52	0.87	0.09
NEIS	30 June	13.64	1.34	0.83	0.06
	7 July	13.64	0.70	0.92	0.07
	14 July	12.88	0.60	0.92	0.07
	21 July	9.66	0.66	0.55	0.06
	28 July	10.36	0.62	0.68	0.07
	4 Aug	11.76	0.92	1.23	0.11

TABLE V.5. SWEAT GLAND (ARM) CLEARANCE OF UREA DURING WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	UREA In Plasma* µg/ml	In Arm Sweat µg/ml	Rate ml/min	µg/min	Clearance ml/min
KACH	29 June	133	300	1.18	353	2.65
	6 July	133	468	1.83	856	6.42
	13 July	133	474	2.38	1128	8.48
	20 July	133	468	1.18	552	4.15
	27 July	133	378	1.58	597	4.48
	3 Aug	133	480	1.83	880	6.61
NEIS	30 June	174	696	0.62	431	2.47
	7 July	174	618	1.30	804	4.62
	14 July	174	534	1.52	813	4.67
	21 July	174	684	0.83	568	3.26
	28 July	174	570	1.10	628	3.62
	4 Aug	174	624	1.33	830	4.77

*Plasma urea was measured on 3 Aug and 4 Aug without correction for ammonia.

TABLE V.6. SWEAT GLAND (TOTAL BODY*) CLEARANCE OF CREATININE DURING WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	CREATININE			
		In Plasma μg/ml	In Total Body Sweat μg/ml	In Total Body Sweat μg/min	Clearance ml/min
KACH	29 June	8.40	0.94	10.03	1.19
	6 July	8.82	1.15	14.46	1.64
	13 July	9.80	0.76	12.82	1.31
	20 July	9.24	0.94	9.70	1.05
	27 July	9.52	0.39	5.47	0.57
	3 Aug	9.52	0.69	11.02	1.16
NELS	30 June	13.64	0.23	2.04	0.15
	7 July	13.64	0.60	7.92	0.58
	14 July	12.88	0.47	7.67	0.60
	21 July	9.66	0.64	6.60	0.68
	28 July	10.36	0.58	7.83	0.76
	4 Aug	11.76	0.54	8.72	0.74

*This excludes arm bag sweat.

TABLE V.7. SWEAT GLAND (TOTAL BODY*) CLEARANCE OF UREA DURING WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	UREA In Plasmaτ µg/ml	µg/ml	Rate ml/min	µg/min	Clearance ml/min
KACH	29 June	133	714	10.67	7618	57
	6 July	133	372	12.57	4676	35
	13 July	133	390	16.87	6579	49
	20 July	133	420	10.32	4334	33
	27 July	133	384	14.03	5388	41
	3 Aug	133	366	15.97	5845	44
NELS	30 June	174	246	8.89	2187	13
	7 July	174	534	13.20	7049	41
	14 July	174	264	16.32	4308	25
	21 July	174	456	10.32	4706	27
	28 July	174	456	13.50	6156	35
	4 Aug	174	462	16.15	7461	43

*Excluding arm bag sweat.

τ Plasma urea was measured on 3 Aug and 4 Aug without correction for ammonia.

TABLE V.8. COMPARISON OF CREATININE CLEARANCE: RENAL AND SWEAT GLAND DURING WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

(VALUES ARE EXPRESSED IN MILLILITERS PLASMA PER MINUTE.)

SUBJECT	DATE	CREATININE CLEARANCE		
		RENAL	SWEAT GLAND	
			Arm	Total Body*
KACH	29 June	105	0.14	1.19
	6 July	166	0.13	1.64
	13 July	181	0.18	1.31
	20 July	176	0.07	1.05
	27 July	169	0.12	0.57
	3 Aug	109	0.09	1.16
NEIS	30 June	75	0.06	0.15
	7 July	53	0.07	0.58
	14 July	62	0.07	0.60
	21 July	109	0.06	0.68
	28 July	97	0.07	0.76
	4 Aug	54	0.11	0.74

*This excludes arm bag sweat.

TABLE V.9. COMPARISON OF UREA CLEARANCE: RENAL AND SWEAT GLAND DURING WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

(VALUES ARE EXPRESSED IN MILLILITERS PLASMA PER MINUTE)

SUBJECT	DATE	UREA CLEARANCE		
		RENAL	SWEAT GLAND	
			Arm	Total Body*
KACH	29 June	93	2.65	57
	6 July	137	6.42	35
	13 July	151	8.48	49
	20 July	154	4.15	33
	27 July	161	4.48	41
	3 Aug	88	6.61	44
NELS	30 June	99	2.47	13
	7 July	53	4.62	41
	14 July	57	4.67	25
	21 July	99	3.26	27
	28 July	77	3.62	35
	4 Aug	49	4.77	43

*This excludes arm bag sweat.

TABLE V.10. COMPARISON OF CREATININE CLEARANCE: RENAL AND SWEAT GLAND DURING WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

(VALUES ARE EXPRESSED AS MILLILITERS PLASMA PER MINUTE AND SQUARE METER OF BODY SURFACE.)

SUBJECT	DATE	CREATININE CLEARANCE		
		RENAL*	SWEAT GLAND	
			Arm†	Total Body‡
KACH	29 June	52	0.64	0.69
	6 July	85	0.61	0.95
	13 July	93	0.83	0.76
	20 July	91	0.31	0.61
	27 July	109	0.61	0.34
	3 Aug	56	0.46	0.67
NEILS	30 June	42	0.27	0.09
	7 July	30	0.30	0.38
	14 July	26	0.23	0.38
	21 July	61	0.26	0.44
	28 July	54	0.30	0.48
	4 Aug	30	0.48	0.47

*Based on total body surface area.
†Based on surface area of arm
‡Based on total body surface area - arm surface area.

TABLE V.11. COMPARISON OF UREA CLEARANCE: RENAL AND SWEAT GLAND DURING WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050.)

(VALUES ARE EXPRESSED AS MILLILITERS PLASMA PER MINUTE AND SQUARE METER OF BODY SURFACE.)

SUBJECT	DATE	UREA CLEARANCE		
		RENAL*	SWEAT GLAND	
			Arm τ	Total Body ‡
KACH	29 June	48	12	33
	6 July	70	29	20
	13 July	77	39	29
	20 July	79	19	19
	27 July	83	20	23
	3 Aug	45	30	25
NELS	30 June	56	11	8
	7 July	30	21	26
	14 July	32	21	16
	21 July	56	15	17
	28 July	43	16	23
	4 Aug	28	22	27

*Based on total body surface area.
τBased on surface area of arm.
‡Based on total body surface area - arm surface area.

sweat glands, the urea clearance is far greater, being up to 50 times the creatinine clearance.

We must conclude that the kidneys and the sweat glands are quite different in their way of clearing creatinine and urea. The kidney clears creatinine more vigorously than it does urea. The sweat glands appear in some fashion, either by failure to filter or by reabsorption, to hold their creatinine clearance to a low value, whereas the urea is secreted almost as rapidly as it is in the urine. Furthermore, urea clearance is correlated with the rate of sweating; creatinine clearance is not.

VI. EXCRETION OF SOLUTES IN SWEAT AND URINE

In discussions of the physiology of the nephron and the sweat gland, it is often necessary to consider two related concepts. These are the total rate of excretion of a solute with time, and its concentration in the urine or sweat. This section will deal first with the rate of excretion.

A. Rates of Excretion of Solutes.

Values of rates of excretion for the sweat glands have been given in Semi-annual Progress Report No. 3, for arm sweat in Table IV.2A for Subject KACH and Table IV.2B for Subject NELS. For total body sweat the corresponding tables are Table IV.5A and IV.5B. These tables are gross rates, not recalculated on the basis of surface area. Those calculations are given for arm sweat in Table IV.3A for Subject KACH and Table IV.3B for Subject NELS. For total body sweat, the corresponding tables are Table IV.6A and IV.6B.

Before turning to solutes, we should note that generally speaking, with increased thermal stress, the minute volume of urine decreased proportionately with the increased rate of sweating.

For urine data on the various solutes see Tables VI.A.1 through VI.A.5. Two types of comparisons are made for urine in Tables VI.A.6 and VI.A.7 and one for sweat in Table VI.A.7. These last two tables summarize the data for previous tables.

In Table VI.A.6, the rate of renal excretion of solutes is compared before and during the 100 minute walk in the hot room. The subjects were provided with adequate water so that the urine volume stayed above 1 ml per minute. The following solutes decreased significantly in rate of excretion with walking: calcium, total nitrogen, and lactate. One solute increased with walking: creatinine. The rest were either not changed or were equivocal: sodium, potassium, chloride, magnesium, phosphorus, ammonia, urea, osmols, and titratable acidity.

In Table VI.A.7, the rates of excretion of solutes in urine and total body sweat are scrutinized in relation to the rate of sweating. The reader may recall that each subject walked six times, once each week. The sweat rates were low for Walks 1 and 4, intermediate for Walks 2 and 5, and high for Walks 3 and 6. Thus six comparisons are possible with change in rate of sweating between Experiments 1,2,and 3, and between Experiments 4,5, and 6.

The following solutes in the urine decreased in rate of excretion with increased sweat rate: sodium, chloride, calcium, and lactate. All the rest either showed no relation or an equivocal one: potassium, magnesium, phosphorus, ammonia, urea, total nitrogen, osmols and creatinine.

For technical reasons, calcium and magnesium in the urine and sweat are being re-measured at the present time.

With increased rates of total body sweating, the total excretion in the sweat of the following solutes increased significantly: sodium, potassium,

TABLE VI.A.1. MINUTE VOLUME, pH, AND TITRABLE ACIDITY IN URINE PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	MINUTE VOLUME ml/min		pH		TITRABLE ACIDITY µEq/min	
		Pre	Post	Pre	Post	Pre	Post
KACH	29 June	__*	0.79	__*	5.61	__*	15.3
	6 July	2.55	3.67	6.75	6.35	4.2	12.7
	13 July	2.98	2.26	6.65	6.55	8.2	12.1
	20 July	1.16	2.33	6.25	5.85	8.5	23.0
	27 July	2.60	2.88	6.45	6.15	9.7	14.9
	3 Aug.	2.19	1.43	6.91	6.65	6.8	8.9
NEIS	30 June	4.63	2.73	5.91	5.79	22.3	12.6
	7 July	2.48	1.74	6.25	5.98	5.9	16.7
	14 July	1.90	2.86	5.70	6.03	14.0	11.9
	21 July	2.20	4.29	5.60	6.00	25.3	12.2
	28 July	4.94	2.85	6.20	6.18	21.1	11.4
	4 Aug.	1.76	1.75	5.70	6.42	17.2	(5.7)$^{\tau}$

* Urine collected only after walk, includes pre-period.

τ Faulty dilution suspected.

TABLE VI.A.2. EXCRETION OF SODIUM, POTASSIUM, AND CHLORIDE IN THE URINE PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

(VALUES ARE EXPRESSED AS MICROEQUIVALENTS PER MINUTE.)

SUBJECT	DATE	Na		K		Cl	
		Pre	Post	Pre	Post	Pre	Post
KACH	29 June	___*	96	___*	60	___*	120
	6 July	99	161	15	37	107	188
	13 July	117	117	93	99	147	166
	20 July	93	168	39	57	117	228
	27 July	135	153	75	84	178	210
	3 Aug.	279	111	102	69	328	148
NEIS	30 June	144	108	102	75	198	92
	7 July	12	12	30	30	25	25
	14 July	123	33	39	57	126	52
	21 July	168	51	57	82	163	104
	28 July	153	39	109	84	168	74
	4 Aug.	69	9	90	45	111	(29)$^{\tau}$

* Urine collected only after walk, includes pre-period

τ Faulty dilution suspected

TABLE VI.A.3. EXCRETION OF MAGNESIUM, CALCIUM, AND INORGANIC PHOSPHATE IN THE URINE PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	Mg * µEq/min		Ca* µEq/min		P µatoms/min	
		Pre	Post	Pre	Post	Pre	Post
KACH	29 June**	—	3.0	—	0.3	—	10.9
	6 July	2.5	4.2	1.1	1.1	6.1	13.2
	13 July	3.5	3.3	0.9	0.8	9.9	14.8
	20 July	2.6	4.1	0.6	0.9	8.2	19.7
	27 July	4.9	4.9	1.1	0.9	8.4	11.1
	3 Aug.	3.6	2.0	0.9	0.5	13.3	22.1
NEIS	30 June	3.8	1.7	0.5	0.3	31.4	7.2
	7 July	0.3	0.3	0.2	0.0	15.5	7.3
	14 July	3.5	4.4	0.8	0.3	20.1	7.6
	21 July	4.7	1.5	0.6	0.5	20.8	12.3
	28 July	4.0	1.5	0.5	0.2	21.9	10.8
	4 Aug.	2.7	0.5	0.3	0.2	20.2	(0.3)$^{\tau}$

* The estimations of calcium and magnesium are being repeated both in urine and in sweat by an improved method.

** Urine collected only after walk, includes pre-period.

τ Faulty dilution suspected.

TABLE VI. A.4. EXCRETION OF AMMONIA, UREA, AND TOTAL NITROGEN IN THE URINE PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	AMMONIA µEq/min		UREA µM/min		TOTAL N mg/min	
		Pre	Post	Pre	Post	Pre	Post
KACH	29 June	___*	22	___*	206	___*	7.0
	6 July	17	39	218	303	7.0	9.0
	13 July	21	39	302	334	11.0	11.0
	20 July	21	47	182	341	7.0	10.0
	27 July	30	45	338	357	11.0	11.0
	3 Aug.	28	24	301	196	13.0	7.0
NELS	30 June	34	30	287	287	13.0	9.0
	7 July	14	14	218	154	5.0	5.0
	14 July	38	27	375	165	12.0	5.0
	21 July	35	32	443	287	13.0	9.0
	28 July	30	24	373	224	12.0	8.0
	4 Aug.	28	18	447	143	12.0	(4.0)$^{\tau}$

* Urine collected only after walk, includes pre-period.

τ Faulty dilution suspected.

TABLE VI.A.5. EXCRETION OF CREATININE, OSMOLS AND LACTATE IN THE URINE PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	CREATININE μEq/min		OSMOLARITY μOsm/min		LACTATE μEq/min	
		Pre	Post	Pre	Post	Pre	Post
KACH	29 June*	—*	885	—*	513	—*	0.3
	6 July	400	1468	495	782	0.3	0.4
	13 July	590	1770	762	789	0.3	0.3
	20 July	543	1629	501	897	0.2	0.4
	27 July	535	1605	801	876	0.3	0.3
	3 Aug.	345	1035	1242	606	0.5	0.3
NEIS	30 June	3.43	10.29	921	567	0.5	0.2
	7 July	2.43	7.29	252	255	0.3	0.2
	14 July	2.68	8.04	753	354	0.2	0.1
	21 July	2.45	10.51	900	635	0.4	0.3
	28 July	3.35	10.05	860	480	0.3	0.2
	4 Aug.	2.13	6.39	747	267	0.4	(0.2)$^{\tau}$

* Urine collected only after walk, includes pre-period.

τ Faulty dilution suspected.

TABLE VI.A.6. URINARY EXCRETION OF SOLUTES: COMPARISON BETWEEN PERIOD BEFORE WALKING AND DURING WALKING. SUMMER 1966. (NASA GRANT NGR 14-005-050)

Solute	Units	Pre vs. Walk
Titratable Acidity	μ Eq/min	5*/11**
Na	μ Eq/min	8/11
K	μ Eq/min	4/11
Cl	μ Eq/min	7/11
Mg	μ Eq/min	8/11
Ca	μ Eq/min	10/11
P	μ atoms/min	6/11
NH_3	μ Eq/min	7/11
Urea	μ M/min	6/11
Total N	μ atoms/min	9/11
Osmols	μ Osm/min	6/11
Lactate	μ Eq/min	9/11
Creatinine	μ g/min	0/11

*Number of comparisons in which the renal excretion decreased.

**Total number of comparisons.

chloride, ammonia, urea, total nitrogen, osmols, lactate, and creatinine. There was no relation for magnesium or calcium with rate of sweating.

The general conclusion to be reached with respect to rate of excretion in the urine is that some solutes appear to be affected by walking, and some independently by rate of sweating. This suggests homeostatic mechanisms relating the muscles and the kidneys on the one hand, and the sweat glands and the kidneys on the other. Perhaps the most intriguing finding is that the renal excretion rate for urea is independent of walking whereas the renal excretion rate of creatinine is accelerated by walking. The renal excretion rate of urea is independent of increased rate of sweating whereas that for creatinine may be diminished with increased rate of sweating, or at least is not changed.

B. Concentration of Solutes in Urine and Sweat.

The second major concept to be considered is the concentrating capacity of the nephron and the sweat glands. Both presumably have the same precursor fluid -- protein-free blood plasma. The way they elaborate urine on the one hand and sweat on the other appears to be similar. A filtrate is worked upon by diffusion, secretion, and reabsorption. Yet the end product is quite different in the relative proportions of the solutes.

Table VI.B.1 gives the data for minute volume, pH and original concentration of titratable acidity in the urine. Table VI.B.2 gives the original urine concentrations for sodium, potassium, and chloride. Table VI.B.3 shows the values for the original concentration in the urine of magnesium, calcium, and phosphorus. Table VI.B.4 gives data for urinary ammonia, urea, and total nitrogen. Table VI.B.5 shows the values for urinary creatinine, osmols, and lactate.

TABLE VI.A.7. RENAL AND SWEAT GLAND EXCRETION OF SOLUTES IN RELATION TO RATES OF SWEATING. SUMMER 1966. (NASA GRANT NGR 14-005-050).

Solute	Units	Urine	Sweat
Na	μEq/min	9*/12**	0/12
K	μEq/min	6/12	1/12
Cl	μEq/min	9/12	0/12
Mg	μEq/min	7/12	5/12
Ca	μEq/min	9/12	6/12
P	μatoms/min	4/12	none in sweat
NH_3	μEq/min	8/12	1/12
Urea	μM/min	7/12	3/12
Total N	μatoms/min	8/12	3/12
Osmols	μOsm/min	8/12	0/12
Lactate	μEq/min	11/12	1/12
Creatinine	μg/min	8/12	3/12

*Number of comparisons in which the renal excretion decreased.

**Total number of comparisons.

The values for the concentration of solutes in total body sweat have been presented previously in Semi-annual Progress Report No. 3 for the period 1 July 1966 to 31 December 1966. For Subject KACH the table was IV.A and for Subject NELS it was IV.B.

To facilitate decisions on changes and to isolate the factors pre- and post-walking and changed rates of sweating, the present Tables VI.B.6 and VI.B.7 have been constructed.

For urine collected before and during walking (Table VI.B.6) the only solute that unequivocally decreased in concentration in the urine was calcium; pH, magnesium, and lactate were suggestively lowered. Ammonia showed an unequivocal increase. No change or an equivocal change was shown by titratable acidity, sodium, potassium, chloride, phosphorus, urea, total nitrogen, creatinine, and osmols.

For urinary changes in concentration with increased rates of sweating see Table VI.B.7. There was a significant increase in pH, and a significant decrease in calcium. There was a suggestive decrease for magnesium. The following solutes showed no relation or an equivocal one: titratable acidity, sodium, potassium, chloride, phosphorus, ammonia, urea, total nitrogen, osmols, lactate, and creatinine.

Turning to concentrations in the sweat with increased rates of total body sweating (Table IV.B.7), a significant increase was shown by pH, sodium. potassium, chloride, and osmols. A significant decrease was shown by calcium, and total nitrogen, with a suggestive decrease in creatinine. The rest were unchanged or equivocal: magnesium, ammonia, urea, and lactate.

TABLE VI.B.1. MINUTE VOLUME, pH, AND ORIGINAL CONCENTRATION OF TITRATABLE ACIDITY IN URINE, PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	MINUTE VOLUME ml/min		pH		TITRATABLE ACIDITY mEq/L	
		Pre	Post	Pre	Post	Pre	Post
KACH	29 June	--*	0.79	--*	5.61	--*	19.4
	6 July	2.55	3.67	6.75	6.35	1.6	3.5
	13 July	2.98	2.26	6.65	6.55	2.8	5.3
	20 July	1.16	2.33	6.25	5.85	7.3	9.9
	27 July	2.60	2.88	6.45	6.15	3.7	5.2
	3 Aug	2.19	1.43	6.91	6.65	3.1	6.2
NEIS	30 June	4.63	2.73	5.91	5.79	4.8	4.6
	7 July	2.48	1.74	6.25	5.98	2.4	9.6
	14 July	1.90	2.86	5.70	6.03	7.4	4.2
	21 July	2.20	4.29	5.60	6.00	11.5	2.8
	28 July	4.94	2.85	6.20	6.18	4.3	4.0
	4 Aug	1.76	1.75	5.70	6.42	9.8	(3.3)τ

*Urine collected only after walk, including pre-period.
τFaulty dilution suspected.

TABLE VI.B.2 ORIGINAL CONCENTRATIONS OF SODIUM, POTASSIUM, AND CHLORIDE IN URINE, PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	SODIUM mEq/L		POTASSIUM mEq/L		CHLORIDE mEq/L	
		Pre	Post	Pre	Post	Pre	Post
KACH	29 June	--*	122.1	--*	76.3	--*	152.5
	6 July	38.7	44.0	5.9	10.0	41.7	51.1
	13 July	39.3	51.8	31.2	43.8	49.5	73.3
	20 July	80.0	72.2	33.6	24.5	100.4	98.2
	27 July	51.5	53.1	28.8	29.2	68.5	73.0
	3 Aug	127.4	77.4	46.6	48.1	149.0	103.4
NELS	30 June	31.0	39.6	22.0	27.5	42.9	33.8
	7 July	4.8	6.9	12.1	17.2	10.1	14.3
	14 July	64.9	11.6	20.6	20.0	66.3	18.3
	21 July	76.4	12.0	25.9	19.0	74.0	24.2
	28 July	31.0	13.7	22.0	29.5	34.0	25.8
	4 Aug	39.3	5.2	51.2	25.8	63.0	16.4

*Urine collected only after walk, includes pre-period.

TABLE VI.B.3. ORIGINAL CONCENTRATIONS OF MAGNESIUM, CALCIUM, AND PHOSPHORUS IN URINE, PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	MAGNESIUM mEq/L		CALCIUM mEq/L		PHOSPHORUS mEq/L	
		Pre	Post	Pre	Post	Pre	Post
KACH	29 June	--*	3.8	--*	0.4	--*	13.7
	6 July	1.0	1.2	0.4	0.3	2.4	3.6
	13 July	1.2	1.5	0.3	0.3	3.3	6.5
	20 July	2.2	1.8	0.5	0.4	7.1	8.5
	27 July	1.9	1.7	0.4	0.3	3.2	3.9
	3 Aug	1.6	1.5	0.4	0.4	6.1	15.4
NELS	30 June	0.9	0.6	0.1	0.1	6.8	2.6
	7 July	0.1	0.2	0.1	0.0	6.3	4.2
	14 July	1.8	1.6	0.4	0.1	10.6	2.7
	21 July	2.2	0.4	0.3	0.1	9.5	2.9
	28 July	0.8	0.5	0.1	0.1	4.4	3.8
	4 Aug	1.6	0.3	0.2	0.1	11.5	(0.2)τ

*Urine collected only after walk, includes pre-period.

τ Faulty dilution suspected.

TABLE VI.B.4 ORIGINAL CONCENTRATIONS OF AMMONIA, UREA, AND TOTAL NITROGEN IN URINE, PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	AMMONIA mEq/L Pre	AMMONIA mEq/L Post	UREA mM/L Pre	UREA mM/L Post	TOTAL NITROGEN g/L Pre	TOTAL NITROGEN g/L Post
KACH	29 June	--*	27.5	--*	261.4	--*	8.3
	6 July	6.7	10.7	85.5	82.5	2.6	2.6
	13 July	7.2	17.1	101.4	147.8	3.7	4.6
	20 July	18.4	20.3	156.7	146.5	6.0	4.4
	27 July	11.5	15.6	130.1	123.9	4.1	3.8
	3 Aug	12.7	16.4	141.5	136.6	6.1	5.0
NELS	30 June	7.4	10.9	62.1	105.3	2.9	3.2
	7 July	5.6	7.9	87.9	88.3	1.9	2.6
	14 July	19.8	9.3	198.0	57.6	6.3	1.9
	21 July	16.1	7.4	201.4	67.0	5.9	2.2
	28 July	6.1	8.5	75.5	78.5	2.5	2.6
	4 Aug	15.7	10.3	254.2	81.9	7.0	2.5

*Urine collected only after walk, includes pre-period.

TABLE VI.B.5. ORIGINAL CONCENTRATIONS OF CREATININE, OSMOLS, AND LACTATE IN URINE, PRE- AND POST-WALK. SUMMER 1966. (NASA GRANT NGR 14-005-050).

SUBJECT	DATE	CREATININE g/L		OSMOLARITY mOsm/L		LACTATE mEq/L	
		Pre	Post	Pre	Post	Pre	Post
KACH	29 June	--*	1.14	--*	653	--*	0.36
	6 July	0.34	0.40	194	213	0.10	0.11
	13 July	0.45	0.78	256	349	0.11	0.13
	20 July	0.76	0.70	431	386	0.21	0.18
	27 July	0.47	0.56	308	304	0.13	0.11
	3 Aug	0.74	0.72	567	422	0.21	0.21
NEILS	30 June	0.21	0.38	199	208	0.10	0.09
	7 July	0.31	0.42	102	146	0.11	0.10
	14 July	0.58	0.28	397	124	0.10	0.04
	21 July	0.52	0.25	409	148	0.13	0.06
	28 July	0.22	0.35	174	169	0.06	0.08
	4 Aug	0.67	0.37	425	153	0.21	0.12

*Urine collected only after walk, includes pre-period.

TABLE VI.B.6. CONCENTRATION OF SOLUTES IN URINE: COMPARISON BETWEEN PERIOD BEFORE WALKING AND DURING WALKING. SUMMER 1966. (NASA GRANT NGR 14-005-050).

Solute	Units	Pre vs. Walk
pH	pH units	8*/11**
Titratable Acidity	mEq/L	5/11
Na	mEq/L	6/11
K	mEq/L	4/11
Cl	mEq/L	7/11
Mg	mEq/L	8/11
Ca	mEq/L	11/11
P	m atoms/L	6/11
NH_3	mEq/L	3/11
Urea	mM/L	7/11
Total N	g/L	7/11
Creatinine	g/L	5/11
Osmols	m Osm/L	7/11
Lactate	mEq/L	8/11

*Number of comparisons in which the renal excretion decreased.

**Total number of comparisons.

TABLE VI.B.7. CONCENTRATION OF SOLUTES IN URINE AND SWEAT IN RELATION TO RATES OF SWEATING. SUMMER 1966. (NASA GRANT NGR 14-005-050).

Solute	Units	Urine	Sweat (Total Body)
pH	pH units	0*/12**	1/12
Titratable Acidity	mEq/L	7/12	not done
Na	mEq/L	7/12	1/12
K	mEq/L	5/12	2/12
Cl	mEq/L	7/12	1/12
Mg	mEq/L	8/12	7/12
Ca	mEq/L	10/12	9/12
P	m atoms/L	6/12	none in sweat
NH_3	mEq/L	6/12	5/12
Urea	mM/L	7/12	7/12
Total N	g/L	7/12	9/12
Osmols	mOsm/L	5/12	1/12
Lactate	mEq/L	7/12	7/12
Creatinine	g/L	5/12	8/12

*Number of comparisons in which the renal excretion decreased.
**Total number of comparisons.

It is clear from these data that some solutes are related in the urine to both walking and rate of sweating, as in the case of calcium and magnesium. Some solutes change with walking, but not increased rate of sweating, such as ammonia. Others in the urine changed with increased sweating but not walking, such as pH.

These data suggest that certain reciprocal relations do exist between the kidneys and the sweat glands in sweating induced by walking plus thermal stress.

With respect to the sweat concentration itself, with increased rate of sweating, the most striking finding is a reverse relationship between increases in Na, K, Cl and osmolar concentration, and decreases in hydrogen ion concentration, calcium, total nitrogen and possibly creatinine. The mechanism for such changes must be only speculative at this time.

VII. GENERAL DISCUSSION ON FACTORS RELATED TO CONCENTRATION OF SOLUTES IN THE SWEAT

There is but little agreement in the literature about sweating on the various physiological factors related to the concentration of solutes in the sweat. Long ago, Johnson, Pitts and Consolazio (1944) stated:

"4. Hypothesis concerning regulation of chloride in sweat. The correlations discussed above suggest that three primary mechanisms regulate the concentration of chloride in sweat. These are: (a) the peripheral factor of skin temperature; (b) a central factor of which rectal temperature and rate of sweating are probably the most important indices; and (c) the factor of individual idiosyncrasy . . . . The interplay of these mechanisms plausibly explains changes heretofore ascribed to duration of work, environmental conditions, intake of water, intake of salt and acclimatization."

The present experiments 22 years later tend to support this old hypothesis. Of course since then neuroendocrine factors have become prominent especially aldosterone and its effects, the nutritional aspect has been emphasized, and much sophistication has been introduced into the story by various workers listed and discussed by Robinson and Robinson (1958).

Examining our present data, we may be able to use a factorial analysis based on the clearance formula: U V/ S, and distinguish changes in total excretion due to increase in volume, increase in concentration, or both. Where the increased excretion is not associated with a change in concentration, the volume must be controlling. Lactate and urea are the most striking molecules in this respect. In both, the total rate of excretion in the sweat increased. At the same time the concentration tended to decrease with increased rate. By contrast, sodium, chloride and osmols increased in both total excretion and concentration. Thus at least two different mechanisms must be at work.

Our next semi-annual report will contain a critical analysis of the work of a number of authors who have written on these points including Robinson and Robinson (1958), Schwartz and Thaysen (1956), Foster (1961,1966), Adams, Johnson, and Sargent (1958), Coltman and Atwell (1965), Custance (1965), Lichton (1957), Dill, Hall and Van Beaumont (1966), Gordon and Cage (1966), Wyndham, Strydom, Morrison, Williams, Bredell, and Peter (1966), Cage and Dobson (1965), and Brusilow and Gordes (1965).

A second vexed point in sweat physiology is the relation between the final concentration in the sweat and what happens to the precursor fluid. We cannot subscribe to the simple mechanical model that uses urea as a "tracer" and movement of water as the sole controller of concentration. The system is much more complex than that, as shown by the example in Table VII.1, which

TABLE VII.1. COMPARISON OF CONCENTRATION OF SOLUTES IN BLOOD PLASMA, URINE, ARM SWEAT, AND BODY SWEAT. SUMMER 1966. (NASA GRANT NGR 14-005-050).

Solute	Units	Plasma	Post-Walk Urine	Arm Sweat	Total Body Sweat
A. KACH: 3 Aug 1966					
Osmolarity	mOsm/L	300	202	115	100
Creatinine	μg/ml	9.5	345	0.5	0.7
Na	mEq/L	140	37	46	37
K	mEq/L	4.7	23	5.4	3.9
Cl	mEq/L	107	49	43	36
Lactate	mEq/L	2.5	0.1	13.8	10.8
Ammonia	mEq/L	0.4*	7.9	2.1	1.9
Urea	mM/L	4.7	65.3	8.0	6.1
pH	pH units	7.40*	6.65	5.92	6.64
B. NEILS: 4 Aug 1966					
Osmolarity	mOsm/L	293	89	148	132
Creatinine	μg/ml	11.8	213	0.9	0.5
Na	mEq/L	140	3	61	54
K	mEq/L	4.7	15	6.2	3.7
Cl	mEq/L	105	9	55	50
Lactate	mEq/L	3.2	0.1	15.8	10.3
Ammonia	mEq/L	0.4*	6.0	2.1	1.2
Urea	mM/L	7.8	47.7	10.4	7.7
pH	pH units	7.40*	6.42	7.50	7.35

*Assumed value, not directly measured.

gives details for one of the six day-long experiments, and compares the concentration of solutes in the plasma, urine, arm sweat, and body sweat. The other five days were quite similar.

Using the clearance formula U V/ S, one can distinguish three groups of solutes: those that are hypertonic to plasma; those that are hypotonic; and those that are isotonic. With respect to urine, the hypertonic solutes were: hydrogen ions, creatinine, potassium, ammonia, and urea. The hypotonic solutes were: osmols, sodium, chloride, and lactate. In the urine there were no isotonic solutes in this experiment.

In the sweat, arm sweat and total body sweat can be considered as similar enough to be lumped together in the discussion. To be sure a discrepancy existed for potassium for Subject KACH, and potassium, urea, and pH for Subject NELS. These discrepancies do not invalidate the argument. The hypertonic solutes were: lactate, ammonia, urea; hydrogen ion was suggestively high in 3 of 4 comparisons. The hypotonic solutes were: osmols, creatinine, sodium, and chloride. The sole isotonic solute seemed to be potassium, although the arm sweat was slightly hypertonic, the total body sweat slightly hypotonic.

The conclusions to be drawn from this experiment and the other five relate to the similarities and dissimilarities between sweat glands and nephrons, and to the elaboration of sweat from the precursor fluid. With respect to acid-base balance (pH, ammonia, lactate), there are differences. The pH alone is not very meaningful. However, urinary ammonia is far higher than sweat ammonia, urinary lactate far lower. With respect to nitrogenous excretion (creatinine, urea), the sweat glands and the nephrons behave completely differently for creatinine, and rather similarly for urea, although the sweat urea is substantially lower in concentration than the urine urea. Finally, with respect to other electrolytes, the kidneys and sweat glands treat sodium and chloride similarly, i.e., they are roughly equivalent in concentration and hypotonic. Osmolarity is rather greater in the urine. A big difference exists for potassium; it is strongly hypertonic for urine, almost isotonic for sweat. Thus, there are striking differences between nephrons and sweat glands in their excretion of solutes.

We cannot see a simple answer to explain the elaboration of sweat. There must simultaneously occur shifts in water, active secretion against an osmotic gradient, and reabsorption with an osmotic gradient to account simultaneously for hypertonicity, isotonicity, and hypotonicity depending on which solute one studies.

Remarkable differences in the sweat glands' handling of different organic acids occur. Adams, Johnson and Sargent (1958) showed that even when the subject is ketotic with a plasma total ketone body concentration of up to 7 mMols per liter, acetoacetate and beta-hydroxybutyrate do not appear in the sweat, although large concentrations are to be found in the urine. By contrast we, in this report, confirm the work of many others regarding lactate. Even at rest, the lactate concentration in sweat is far higher than it is in blood plasma. Finally, we have shown that in "pure sweat" as we define it, that is, clear and without microscopic sediment, virtually no inorganic phosphate, acid hydrolyzable phosphate, or total organic phosphate can be demonstrated in sweat. Any hypothesis on sweat production will have to account for phenomena like those listed for ketone bodies, lactate, and phosphate.

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APPENDIX A

LIST OF TABLES IN THIS REPORT

APPENDIX A

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